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Risk-Based Assessment of Appropriate Fuel Hydrocarbon Cleanup Strategies for the Naval Exchange Gasoline Station Naval Construction Battalion Center Port Hueneme, California

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Submitted to the Naval Facilities Engineering Services Center
Port Hueneme, California

June 1998

*University of California, Santa Barbara

**Malcolm Pirnie Corporation, Emeryville, California

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*****U.S. Environmental Protection Agency, San Francisco, California



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1. Program Overview

1.1. Introduction

In June 1994, the State Water Resource Control Board (SWRCB) contracted with the Lawrence Livermore National Laboratory/University of California (LLNL/UC) Leaking Underground Fuel Tank (LUFT) Team to study the cleanup of LUFTs in California. The study consisted of data collection and analysis from LUFT cases and a review of other studies on LUFT cleanups. Two final reports were submitted to the SWRCB in October and November 1995. These reports were entitled: *Recommendations To Improve the Cleanup Process for California's Leaking Underground Fuel Tanks (LUFTs)* (Rice et al., 1995a), and *California Leaking Underground Fuel Tank (LUFT) Historical Case Analysis* (Rice et al., 1995b).

1.2. LUFT Demonstration Cleanup Program

1.2.1. Background

One of the important recommendations of this study was to identify a series of LUFT demonstration sites and to form a panel of experts made up of scientific professionals from universities, private industry, and Federal and State regulatory agencies. This panel would provide professional interpretations and recommendations regarding LUFT evaluations and closures at demonstration sites.

As a result of this recommendation, ten Department of Defense (DoD) sites were selected. Site selection was coordinated through the California Military Environmental Coordination Committee (CMECC) Water Process Action Team (PAT). Sites were selected to represent each branch of the military services with bases in California, as well as a number of Regional Water Quality Control Boards (RWQCB) and the diverse hydrogeologic settings in California where fuel hydrocarbon contaminant (FHC) cleanup problems occur. The Naval Exchange (NEX) Site at Port Hueneme, within the Los Angeles RWQCB, is one of the sites selected to participate in the DoD Petroleum Hydrocarbon Cleanup Demonstration (PHCD) Program. This program will be referred to as the DoD LUFT Demonstration Cleanup Program.

The other sites selected and their corresponding RWQCB region are:

- Army Presidio at San Francisco, San Francisco RWQCB.
- Barstow Marine Corps Logistic Center, Lahontan RWQCB.
- Camp Pendleton Marine Corps Base, San Diego RWQCB.
- Castle Air Force Base, Central Valley RWQCB.
- El Toro Marine Corps Air Station, Santa Ana RWQCB.
- George Air Force Base, Lahontan RWQCB.
- China Lake Naval Weapons Center, Lahontan RWQCB.
- Travis Air Force Base, San Francisco RWQCB.
- Vandenberg Air Force Base, Central Coast RWQCB.

The Expert Committee (EC) selected to evaluate the selected demonstration sites are:

- Dr. Stephen Cullen, UC, Santa Barbara, Hydrogeologist; member of LLNL/UC LUFT Team with expertise in vadose zone FHC transport mechanisms and passive bioremediation processes.
- Dr. Lorne G. Everett, UC, Santa Barbara, Hydrogeologist; Director, Vadose Zone Research Laboratory, member of LLNL/UC LUFT Team, Chief Hydrologist with Geraghty & Miller, Inc., with expertise in vadose zone FHC transport mechanisms and passive bioremediation processes.
- Dr. Paul Johnson, Arizona State University, Chemical Engineer; primary author of *American Society for Testing and Materials (ASTM) RBCA* guidance, with expertise in chemical fate and transport..
- Dr. William E. Kastenberg, UC, Berkeley, Professor and Chairman, Department of Nuclear Engineering; member of LLNL/UC LUFT Team, with expertise in environmental decision making and decision analysis processes.
- Dr. Michael Kavanaugh, former Chairman, National Research Council Alternatives for Groundwater Cleanup Committee; Vice President, Malcolm Pirnie, Inc., with expertise in evaluation of groundwater remediation alternatives and environmental decision making processes.
- Dr. Walt McNab, LLNL, Environmental Scientist, with expertise in the evaluation of passive bioremediation processes.
- Mr. David W. Rice, LLNL, Environmental Scientist; Project Director SWRCB LUFT Re-Evaluation Project; LLNL/UC LUFT Team member; DoD FHC Demonstration Program Coordinator.
- Mr. Matthew Small, U.S. EPA Region IX, Hydrogeologist; Co-Chairman of U.S. EPA Remediation by Natural Attenuation Committee, with expertise in risk-based corrective action and passive bioremediation.

1.2.2. Risk-Based Corrective Action

The LLNL/UC recommendations report concluded that risk-based corrective action (RBCA) provides a framework to link cleanup decisions to risk. The DoD LUFT Demonstration Cleanup Program provides a series of sites where the application of a risk-based cleanup approach can be demonstrated.

For a risk to exist, there must be a source of a hazard, a receptor, and a pathway that connects the two. All three factors must be addressed to determine whether a LUFT release poses a risk to human health, safety, or the environment. If the source, pathway, or receptor are at all times absent, there is, by definition, no risk. The distinction between sources, pathways, and receptors may be context-dependent in many cases and therefore must be carefully defined. For purposes of the present assessment, definitions of these terms are developed by working backward from the receptor to the source:

Receptor: Human or ecological risk receptors which may potentially be subject to damage by exposure to hydrocarbons via ingestion, inhalation, or absorption. This definition also specifically includes water-supply wells because it must be assumed that humans will be ingesting the water from these wells.

Pathways: Physical migration routes of contaminants from sources to risk receptors. This definition specifically includes the groundwater environment downgradient of the source that provides a medium through which dissolved contaminants may migrate to water-supply wells, as well as to surface water bodies which may serve as ecological risk pathways. The definition also includes the vadose zone in the immediate vicinity of the source, where vapor migration routes to nearby human receptors may exist.

Sources: Points of entry of contaminants into possible exposure pathways. In the case of hydrocarbon releases associated with LUFT sites, separate-phase hydrocarbon product which can either dissolve into the aqueous phase or volatilize into the gaseous phase constitutes a source. Primary sources will include underground tanks and associated piping; secondary sources will include any separate-phase hydrocarbon or free-product material residing within sediment pores.

From a mathematical viewpoint, sources and receptors represent boundary conditions for the problem of interest (influx and outflux, respectively); pathways represent the problem domain. Thus, in some special situations, the dissolved plume in groundwater may represent a source, such as in the case of Henry's law partitioning of contaminants from the aqueous phase into the gaseous phase. On the other hand, hydrocarbons which have adsorbed onto sediment surfaces from the aqueous phase cannot be regarded as potential sources in most situations according to this definition, but rather exist as part of the pathway.

Risk characterization is defined as an information synthesis and summary about a potentially hazardous situation that addresses the needs and interests of decision makers and of interested and affected parties. Risk characterization is a prelude to cleanup decision making and depends on an iterative, analytic, and deliberative process. This process attempts to gather all relevant data so the decision makers may then choose the best risk-management approach.

1.2.3. The Appropriate Use of Passive Bioremediation

The California LUFT cleanup study also concluded that with rare exceptions, petroleum fuel releases will naturally degrade (passively bioremediate) in California's subsurface environments. The DOD LUFT Demonstration Cleanup Program provides sites where the appropriate use of passive bioremediation can be evaluated.

Passive bioremediation can control ground water contamination in two distinct ways:

- First, passive bioremediation substantially lowers the risk posed to downgradient risk receptors through plume stabilization¹.
- Second, passive bioremediation actively destroys fuel hydrocarbon mass in the subsurface, leading to remediation of contamination over time (e.g., eventual contaminant concentration decline and depletion of the dissolved hydrocarbon plume). From a risk management viewpoint, the stabilization of the dissolved plume and associated reduction in exposure potential is the most important contribution of passive bioremediation.

The role of passive bioremediation in controlling the behavior of dissolved hydrocarbon plumes may be evaluated through both primary and secondary field evidence.

- Primary evidence includes quantitative evaluation of plume stability or plume shrinkage based upon trends in historical groundwater contaminant concentration data.
- Secondary evidence includes indirect indicators of passive bioremediation, such as variations in key geochemical parameters (dissolved oxygen, nitrate, sulfate, iron, manganese, methane, alkalinity/carbon dioxide, Eh, pH) between measurements in fuel hydrocarbon-impacted areas and background.

Although primary evidence of plume stability or decline generally provides the strongest arguments to support natural attenuation at a given site, such evidence may not be available because adequate historical groundwater monitoring may not exist. In these cases, short-term monitoring data providing secondary lines of evidence, in conjunction with modeling where appropriate, may

¹ Even in the presence of a continuous constant source of fuel hydrocarbons (e.g., dissolution of residual free-product components trapped in the soil matrix), a groundwater plume subject to passive bioremediation will reach a steady-state condition in which plume length becomes stable. This will occur when the rate of hydrocarbon influx from dissolution of the residual free-product source is balanced by the rate of mass loss via passive bioremediation, integrated across the entire spatial extent of the plume.

support a hypothesis for the occurrence of passive bioremediation. Consequently, means for assessing the role of passive bioremediation in controlling risk by secondary lines of evidence should be fully explored at such sites.

Appropriate use of passive bioremediation as a remedial alternative requires the same care and professional judgment as the use of any other remedial alternative. This includes site characterization, assessment of potential risks, comparison with other remedial alternatives, evaluation of cost effectiveness, and the potential for bioremediation to reach remedial goals. Monitoring process and contingency planning must be considered as well.

Passive bioremediation may be implemented at a given petroleum release site either as a stand-alone remedial action or in combination with other remedial actions. The need for active source removal must also be addressed on a site-by-site basis. Source removal includes removing leaking tanks and associated pipelines, and any remaining free product and petroleum fuel saturated soil, as much as economically and technically feasible. When properly used, passive bioremediation can help manage risk and achieve remedial goals.

1.2.4. The DoD LUFT Demonstration Cleanup Program Steps

The demonstration program process can be summarized in the following nine steps:

- Step 1: Site scoping meeting with site staff, regulators, and EC staff representatives. Develop and discuss site conceptual model. Identify and discuss pathways and receptors of concern.
- Step 2: Risk Based Corrective Action (RBCA) training for DoD Petroleum Hydrocarbon Cleanup Demonstration Program (PHCDP) participants.
- Step 3: Site staff and contractors prepare the data package. EC staff reviews available data and identifies data gaps needed to apply a risk-based cleanup approach.
- Step 4: EC visits site and receives briefing, onsite characterization, conceptual model, and pathways and receptors of concern. Site tour is included in this briefing. Following EC's visit, a site characterization report is prepared by the EC containing recommendations for further data collection, if needed (See Appendices A and B).
- Step 5: EC staff applies a risk-based cleanup approach to the Site using best available data.
- Step 6: EC staff evaluates the natural attenuation potential for the Site using best available data. An estimate of the time to clean up and the uncertainty associated with this estimate will be made. Sampling and monitoring procedures to support intrinsic bioremediation for the Site will be identified.
- Step 7: Based on the concept of applied source, pathways, and receptors as to potential hazards, site-specific findings regarding natural attenuation potential, and discussion with regulators, the EC shall provide its recommendations for an appropriate risk-management strategy at the Site and the set of actions needed to achieve site closure. The EC will present its recommendations at an appropriate forum.
- Step 8: The EC will provide a DoD LUFT Demonstration Cleanup Program overall evaluation comparing the effectiveness of risk-based cleanup at each site in the program. An estimation of the cost savings using risk-based cleanup protocols will be compared to baseline approaches. An estimation of the value of the remediated water will be made.
- Step 9: The EC Staff will produce a DoD Risk Execution Strategy for Clean-Up of the Environment (RESCUE) implementation guide and accompanying procedures manual (Phase I, Petroleum) that can be used in California and in other states by military bases.

2. Site Overview

2.1. Background and Site History

The Naval Exchange Battalion Center (NCBC), Port Hueneme, is located in Ventura County, California, approximately 45 miles northwest of the city of Los Angeles. Established in 1942 to meet World War II military requirements, NCBC Port Hueneme consists of 1,647 acres of coastal land, approximately 5 miles northwest of the Santa Monica Mountains in Southern California. The installation consists of 750 buildings and supports a work force of approximately 10,000 personnel. Major responsibilities of NCBC Port Hueneme include training military technical staff, outfitting Naval Mobile Construction Battalions and Seabee teams, providing supply and administrative services, and providing logistical support needed to deploy the Pacific Naval Construction Force.

Several sites at NCBC Port Hueneme may have soil and groundwater contaminated by historical military activities. These sites have been investigated under the Installation Restoration Program (IRP) in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and state and local petroleum UST unauthorized release cleanup programs. More than 70 USTs have been historically used to store fuel products at NCBC Port Hueneme. NCBC Port Hueneme is actively implementing an UST program and has removed all known inactive and abandoned USTs. The former UST sites are in various stages of investigation. At NCBC Port Hueneme, the RWQCB is the lead regulatory agency for UST sites involving contaminant releases. The NEX Gasoline Station, has operated at its current location since 1950 when two 7,400-gallon USTs were installed. During its operation, 12 tanks have been installed for the storage of gasoline. These tanks varied in capacity from 350 to 12,000 gallons. Currently, only four tanks are present at the Site. The remaining tanks were removed in 1992 and 1993.

The NEX Gasoline Station is located in the vicinity of Building 797, at the southeastern intersection of 23rd Avenue and Dodson Street. Site 797 has four active USTs (797-11 through 797-14) which store gasoline. It had eight abandoned USTs (797-01 through 797-5, 797-07, 797-08, and 797-16), which were removed.

UST 797-01 had a 12,000-gallon capacity and was located northwest of the gasoline pumps at Building 797. The base of UST 797-01 was located at a depth of approximately 13 feet below ground surface (bgs). USTs 797-02, 797-03, 797-04, and 797-05 had 10,000-gallon capacities. They were located east of the gasoline pumps at a depth of approximately 12 feet bgs (measured from the base of the USTs). USTs 797-07 and 797-08 had 7,400-gallon capacities; they were located northwest of Building 797 and immediately west of the gasoline pumps, at a depth of approximately 12 feet bgs. UST 797-16 had a 350-gallon capacity.

2.1.1. U.S. Navy National Test Site

Over the past three years the United States Navy has operated its National Test Site at Port Hueneme. The National Test Site was set up originally to evaluate hydrocarbon remediation technologies. The National Test Site has been internationally reviewed and has resulted in several highly successful demonstrations of cost-effective hydrocarbon remediation strategies. Since the free product and dissolved product with respect to benzene, toluene, ethylbenzene, xylene (BTEX) and the methyl *tertiary* butyl ether (MTBE) plume represent a unique opportunity, several existing and planned subsurface remediation strategies will be demonstrated at the Site. Extended discussion with the RWQCB has resulted in agreements wherein the National Test Site may operate with the support of the regulators in the area.

2.2. Site

2.2.1. Geology and Hydrogeology

An understanding of near-surface geology in the vicinity of the NEX gasoline station is based on information derived from site investigations. The geology within the upper 30 feet of the Site consists of unconsolidated sands, silts, and clays with minor amounts of gravel and fill material. The unconsolidated deposits are typically represented by three units: (1) an upper fine-grained, silty sand unit encountered from ground surface to a maximum depth of 5 feet; (2) an intermediate fine- to coarse-grained sand unit; and (3) an underlying sandy to silty clay unit generally encountered from 20 to 25 feet bgs. A generalized geologic cross section for NCBC Port Hueneme has been provided.

An understanding of the hydrogeology in the vicinity of the NEX Gasoline Station is based on information derived from previous investigations. A generalized hydrogeologic cross section for NCBC Port Hueneme has been provided.

The most important hydrostratigraphic unit at the NEX Gasoline Station is the semiperched aquifer, a water-table aquifer that has been investigated during several studies at the Site. The semiperched aquifer consists of coarse to fine sands within a generally fining-upward sequence. Groundwater is typically encountered at 8 to 10 feet bgs (10 feet above mean sea level [MSL]). The water quality in the semiperched aquifer is brackish to saline. Total dissolved solids concentrations at the Site are approximately 2,000 milligrams per liter (mg/L) and total hardness as calcium carbonate is approximately 1,000 mg/L. According to available information, no known water-supply wells are completed in the semiperched aquifer in the NCBC Port Hueneme area. The semiperched aquifer may discharge to drainage ditches, harbors, and beaches in the vicinity of NCBC Port Hueneme.

Groundwater flow in the semiperched aquifer is generally toward the southwest. The direction of groundwater flow is influenced by tidal fluctuations at the western margin of the base, but tidal influences have not been observed at the NEX Gasoline Station. The groundwater gradient varies between 0.002 and 0.003 feet/foot across the NEX Gasoline Station. In the vicinity of the NEX Gasoline Station, the hydraulic conductivity of the semiperched aquifer is estimated at 0.002 to 0.003 gallons per day per square foot, based on the 50-hour pumping test. Four-inch diameter monitoring wells at the Site have sustained pumping rates in excess of 30 gpm during pump testing. The rate of groundwater migration is estimated to be on the order of 0.1 feet per day. The recent evaluations of the MTBE migration rate places the groundwater velocity in the range of 1 foot per day. This inconsistency between area groundwater investigations and the rate of MTBE migration can be explained by the fact that the BTEX and MTBE appear to be following a buried stream channel which has a higher permeability than the surrounding sediments. The nearest known exposure points for groundwater in the semiperched aquifer are drainage ditches along Pleasant Valley Road and Pennsylvania Road.

Immediately underlying the semiperched aquifer is a relatively thick aquitard known as the "clay cap," which is consistently found at a depth of about 20 feet at the Site. The aquitard ranges in thickness from 20 to 50 feet at NCBC Port Hueneme and consists of silt and clay with lenses of fine- to medium-grained sand. The "clay cap" has been identified at several locations within NCBC Port Hueneme and is thought to be laterally continuous across the base.

Two aquifer systems separated by an unconformity underlie the semiperched aquifer and "clay cap" aquitard. The upper aquifer system consists of the Oxnard and Mugu aquifers, and the lower aquifer system includes the Hueneme and Fox Canyon aquifers. Artesian conditions reportedly exist between the underlying aquifers and the "clay cap" with potentiometric levels ranging from 20 feet above MSL to 5 feet above MSL.

The climate in the vicinity of NCBC Port Hueneme and the NEX Gasoline Station is moderately dry, with mild, moist winters and warm, dry summers. The average annual precipitation is 10.5 inches with the heaviest rainfall occurring in January and the least rainfall in July and August. Minimal to low rainfall percolation is likely for the region, which implies a low probability for significant recharge of soil moisture. Increased rainfall infiltration would be expected in association with heavy rainstorms and during years when total rainfall exceeds the average. Infiltration in the immediate vicinity of the NEX Gasoline Station is reduced due to a large amount of pavement, which is estimated to cover more than 90 percent of the Site.

2.2.2. Distribution of Contaminants in Soil and Groundwater

Soil samples collected at the NEX Gasoline Station were analyzed for total petroleum hydrocarbons (TPH) purgeable, BTEX; volatile organic compounds (VOCs), contract laboratory program (CLP) metals, and organic lead. Analytical results indicated elevated levels of TPH purgeable, BTEX, and VOCs.

Groundwater encountered in the tank excavations at the NEX Gasoline Station exhibited a dark oily sheen. The analytical results indicate elevated levels of TPH purgeable, BTEX, MTBE, and other VOCs. Groundwater sampling has occurred at the NEX Gasoline Station on a regular basis (in most cases quarterly or more frequently) since October 1991.

The groundwater data collected to date indicate that the petroleum hydrocarbon plume at the NEX Gasoline Station has stabilized over time and that MTBE concentrations on the downgradient or leading edge of the plume have increased between 1994 and 1997. Additionally, recently collected data indicate that oxygen and nitrates are nearly depleted in certain portions of the petroleum hydrocarbon plume. This is indicative of anaerobic or near anaerobic environments. The extent of free product within the NEX Gasoline Station petroleum hydrocarbon plume is not currently delineated due to the effects of the experimental remediation systems. The presence or absence of free product seems to be closely associated with seasonal groundwater fluctuations and periods of heavy rainfall.

3. Site Conceptual Model

A well defined conceptual model of a site contains sufficient information to: (1) identify sources of the contamination, (2) determine the nature and extent of the contamination, (3) identify the dominant fate and transport characteristics of the site, (4) specify potential exposure pathways, and (5) identify potential receptors that may be impacted by the contamination. A conceptual model for the NEX Site has not yet been fully developed, in part because of uncertainties related to the MTBE anomalies regarding the distribution of contaminants in the groundwater. A summary of key components of the Site conceptual model is provided in this section.

3.1. Sources

3.1.1. Primary Sources

The primary sources of FHC contamination at the Site have been identified. FHC releases from former USTs previously located in the vicinity of Building 797 and associated product piping likely caused contamination of the groundwater beneath these tanks. These primary sources have been removed or eliminated including contaminated soil in the immediate vicinity of the former USTs. The EC has been provided evidence that the newly installed tanks have passed tank leak detection testing, and that these tanks will meet EPA's 1998 mandated UST management requirements.

3.1.2. Secondary Sources

The secondary sources of FHC contamination at the NCBC Port Hueneme NEX site include contaminated soil, free product, and dissolved phase BTEX contamination. Contamination in the vadose zone below the tanks has been identified and quantified. However, in the distal portions of the plume, the free-product distribution is incomplete because the various remediation technologies that have been evaluated at the site may have disturbed this distribution. The characterization data available indicates that the free-product distribution has receded in length and is stabilized. The dissolved BTEX contamination in groundwater is distributed in a long and relatively narrow plume that has followed a buried paleolithic stream channel. In addition, the BTEX has been shown to have a relatively shallow distribution throughout its length. As a result, the BTEX plume exceeds the range of plume lengths typically associated with LUFT releases reported in Rice et al., 1995a.

3.2. Exposure Pathways

Human health or ecological risks arise when a complete exposure pathway exists connecting a point of chemical release to a potential receptor. At this Site, potential exposure pathways include the following:

- Discharge to drainage ditches.
- Inhalation of FHC vapors migrating through the vadose zone.
- Ingestion of FHC constituents present in the water table aquifer.
- Ingestion of FHC constituents possibly present in the deeper aquifer.

Migration of FHCs to the deeper aquifer is unlikely given the thickness of the confining clay layer beneath the water table and thus, this latter exposure pathway is likely incomplete.

Other exposure pathways that could be considered include incidental ingestion of contaminated soil, dermal contact with contaminated soil, and inhalation of wind-blown particulates. None of these exposure pathways are pertinent to this Site because the only medium of concern at this time is shallow groundwater. Soil sampling results confirm that contaminated soil is not an issue at this Site.

3.3. Receptors

According to information prepared for the EC, there are no water-supply wells within 1.5 miles of the NEX Site. The shallow groundwater is not likely to be used as a drinking water source in the future because of poor quality (TDS greater than 1,200 mg/L) and because the Site currently has an extensive water-supply system, relying on city water extracted from the deeper regional aquifer. The water from the shallow aquifer could potentially be used for non-potable uses, however. Thus, risks to human health from ingestion of water is not an immediate issue at this Site. If the water were used for irrigation, volatilization of the BTEX compounds and MTBE would occur, and human exposure is conceivable.

A review of old maps have indicated the presence of an abandoned water-supply well in the vicinity of the contamination plume. After a thorough literature review based on older base documents, counter documents, and regional documents evaluation, it was determined that an old agricultural well could exist within the confines of the plume. If this aged well in fact was in existence, it would offer the opportunity for cross migration of contamination from the upper water bearing units to the lower drinking water aquifers. As such two major field investigations were conducted to locate the abandoned water-supply well. Using sophisticated geophysical techniques, a large areal distribution was evaluated to ensure that the abandoned well would be identified if

present. The results of this major investigation did not result in locating the abandoned well and its existence is deemed to have been an error.

Migration of vapors from the subsurface could reach human receptors who live on the base in areas overlying or near the BTEX and MTBE plumes. One area of concern is the nearby Parade Ground, located above the BTEX & MTBE plume. Volatilization of BTEX in the subsurface and migration of the organic vapors to the ground surface is plausible, although soil gas data does not support this hypothesis.

In summary, potential receptors include current or future onsite workers, and Navy personnel at the Parade Ground who are located within the areal extent of the BTEX plume. In addition, potential ecological receptors should be considered if the shallow groundwater reaches the drainage ditches.

Port Hueneme should conduct a baseline risk assessment, consistent with EPA guidance on human health and ecological risk. The report should summarize estimates of potential human health and ecological risks.

4. Risk Analyses and Management

4.1. Fate and Transport of Contaminants

An important component of assessing potential risks to human health and the environment at contaminated sites and determining appropriate risk-management strategies is an evaluation of the fate of constituents of concern (COCs) as they migrate from the point of release to the potential receptor via an exposure pathway. At this Site, COCs include BTEX and MTBE and each of these chemicals is subjected to various transport and degradation processes that influence the rate of migration, and that control the ultimate fate of the chemical in the subsurface. At this Site, the two impacted media include the water table aquifer, and site soils. The two principal exposure pathways are via groundwater and soil vapor emissions. Based on Site data, the likely fate of the COCs in these two exposure pathways can be inferred.

4.1.1. Groundwater

Completion of the groundwater exposure pathway requires that the COCs migrate from the point of release to the receptor. At this Site, because groundwater is not likely to be used for domestic use now or in the foreseeable future, the ingestion exposure pathway is incomplete. Assuming, however, that the water in the affected shallow water table aquifer is used in the distant future, a completed pathway may only occur if the COCs are not subject to degradation processes that essentially halt the rate of COC migration, or cause a reversal in the movement of the plume, that is, the plume may either stabilize, or begin to decrease in size. As noted previously (Rice et al., 1995a), biodegradation of FHCs in the groundwater due to the presence of indigenous microorganisms, tends to limit the distance that most dissolved hydrocarbons migrate, if the primary source(s) have been removed. When the rate of degradation of FHCs begins to equal or exceed the rate of input of dissolved FHCs from secondary sources, the apparent FHC plume may stabilize, or begin to decrease in size.

Groundwater data collected at the Site indicate that biodegradation of the FHCs is probably occurring. The changes in the concentration of electron acceptors suggest that biodegradation of these compounds was occurring.

More recent groundwater monitoring data also support the hypothesis that passive biodegradation is occurring at various locations within the apparent BTEX and TPH purgeable plumes. These data are consistent with the hypothesis that natural attenuation has occurred and is

occurring at the boundary of the BTEX plume. In contrast to the apparent natural degradation of BTEX compounds, MTBE results from monitor wells suggest that MTBE is still migrating away from the source.

Thus, the data support a hypothesis of passive biodegradation of FHCs in the BTEX plume. As noted previously, significant residual FHCs persist in the groundwater. However, because the primary source has been removed, and because both biodegradation and volatilization processes may be acting on the residual FHCs, the BTEX plume caused by this secondary source may be stabilizing.

In contrast to the behavior of the BTEX and TPH_g plumes which appear to be stable or decreasing in size in some areas of the BTEX plume, the fate of the MTBE at the Site is uncertain. It appears that the MTBE plume may still be migrating, and MTBE appears to have migrated 2,000 feet past the BTEX plume. Thus, monitoring data does not indicate that MTBE has ceased migrating, and the potential for continued impacts to shallow groundwater quality persists.

4.1.2. Soil Vapor

Given the known and inferred presence of residual product in the groundwater, releases of BTEX, MTBE, and other volatile FHCs into the soil gas would be expected. However, the soil gas data show no evidence of BTEX or MTBE in the soil gas, although methane levels from many of the samples were above background levels. It is possible that BTEX vapors being released from the water table are degraded before reaching the shallow soils. Alternatively, the quantities of residual FHCs may be sufficiently reduced such that the vapor flux to the surface from the residual FHCs may be too small to detect. A third hypothesis is that groundwater elevations have increased over the past few years, and the residual FHCs have become submerged, thus inhibiting the release of VOCs into the soil gas. This last hypothesis is supported by changes in groundwater elevation due to heavy rains over the past few years. In any event, the soil gas data has shown that this exposure pathway is currently unlikely to cause the release of BTEX compounds or MTBE at levels representing any significant health risks to onsite and offsite receptors. Should the groundwater elevations decrease in the future, it is possible that releases of VOCs to the soil gas could occur. The magnitude of such a release cannot be easily estimated.

4.2. Remedial Goals

A second key issue that must be addressed to determine appropriate risk-management strategies for a contaminated site is establishing remedial or cleanup goals that must be met before the site may be considered closed. Cleanup requirements are set by states to ensure that sufficient contamination is removed to protect human health and the environment. Other factors that may be considered include, state-specific considerations such as potential use of the groundwater, groundwater yield, aquifer beneficial use designation, cleanup costs versus risks, technical feasibility of cleanup, available expertise, available funding, permitting, and future land use. Generally, guidance is available from the states or EPA which establishes the process for setting remedial goals. At National Priority List sites managed under the Superfund statutes, the process has been clearly established. For UST sites alternative approaches can be used by responsible parties, such as the use of a risk-based decision process.

The cleanup goals set by states usually fall into one of three broad categories: (1) technology based goals, which are based on the detection limits of analytical laboratory equipment (examples include the use of maximum contaminant levels under the Safe Drinking Water Act); (2) subjective goals, which are often adopted based on technology limits or in the absence of another mechanism; these standards may require cleanup to non-detectable or background levels; and (3) risk-based goals, which can be either an overall goal based on conservative yet realistic exposure and toxicity analysis, or site-specific goals based on site-specific conditions, land use, and exposure scenarios.

To establish a basis for site closure, the remedial goals must be satisfied either at all locations throughout the plume or at some boundary which the plume cannot be allowed to migrate beyond, for example, a property boundary. Remedial goals may also include some time frame when the goals must be met. If conditions at the site do not exceed remedial goals, the site will usually receive a status of “no further action required at this time.” If site conditions exceed remedial goals, then several options exist (Small, 1995):

Cleanup to background or non-detect: This approach is very protective of human health and the environment, but can often prove to be prohibitively expensive or technically infeasible.

Cleanup to an overall or generic goal: This approach is also protective, feasible in many cases, and generally less expensive than cleanup to background or non-detect levels. However, achieving these levels, which are often specified as maximum contaminant levels, may still prove to be prohibitively expensive, or even technically infeasible for some sites.

Cleanup to a site-specific goal: The protectiveness of this approach is usually based on specified land uses and may need to be re-evaluated if changes occur. The cleanup levels are often more feasible and generally less expensive to achieve. However, this approach requires site-specific exposure and risk assessment to determine threats and impacts. The acceptability of such an assessment to some stakeholders at a site may be limited.

Risk management or containment: When contaminant concentrations exceed the remedial goals, but such goals cannot feasibly be achieved, then risk management through containment of contamination to prevent further migration may be an option. Active containment systems are often expensive to install and maintain and require long-term institutional control. Passive containment systems are less expensive but have uncertain durability for long-term containment. The continued presence of contamination in the subsurface may also decrease the value of the property.

No Action: In some instances, no remedial actions, including monitoring, may be needed because of no or *de minimus* future risks to human health and the environment. As with monitored natural attenuation, this approach may require site-specific exposure and risk assessment to determine whether the site poses unacceptable threats to public health and the environment.

4.3. Remedial Technology or Process Selection

If contaminant concentrations exceed remedial goals and cleanup is required, then a cleanup technology must be selected based on the information obtained from site assessment and characterization. This technology should be selected based on the ability to meet remedial goals, site conditions, and physio-chemical properties of the contaminants. The technology should not create additional hazards (e.g., air sparging without soil vapor extraction that may potentially transport vapors into buildings).

The technology should ideally perform this task quickly, efficiently, and cost effectively. It is also important to give some consideration to how the cleanup technology or process actually accomplishes concentration reductions and where the removed contaminants or by products are actually going. There are four basic alternatives:

1. Reuse/recycling.
2. Waste destruction (or conversion).
3. Media transfer.
4. Waste disposal.

Media transfer and disposal options may simply move the contamination to another location where it will have to be cleaned up again. Whereas reuse, recycling, and destruction technologies or processes offer more long-term or permanent solutions.

Monitored natural attenuation or passive bioremediation may provide cost effective containment at some sites. In some instances where contamination exceeds remedial goals, but no immediate threats or impacts are identified, it may be acceptable to allow contamination to remain in place without active remediation. Monitored natural dilution, attenuation, and degradation processes are allowed to slowly reduce concentration levels. However, this approach may require site-specific exposure and risk assessment to determine threats and impacts to public health and the environment.

4.4. Remedial Action Alternatives for NCBC NEX Site

Remedial goals to reach closure have not yet been established for the groundwater at the NEX Site, which includes the contaminated shallow aquifer. Options include: (1) cleanup to background, that is, complete removal of all FHCs; (2) cleanup to maximum contaminant levels for the COCs at the Site (BTEX and MTBE); and (3) risk-based goals, with the option of applying these goals throughout the aquifer, or at the property boundary. Depending on the agreed upon goal, several remedial options could be pursued at this Site.

Alternative 1: Cleanup to Background Throughout the Plume

From a resource protection perspective, this goal may often be preferred by regulatory agencies. However, achieving this goal to reach closure within a reasonable time frame is not likely to be feasible. Furthermore, at this Site, there are minimal risks to human health and the environment, despite the presence of significant quantities of FHCs in both the dissolved plume and residual hydrocarbons trapped in the soils beneath the Site. Therefore, accepting this closure goal, and undertaking the necessary remedial actions, would not be an appropriate use of financial resources. The costs far exceed the benefits because of the limited uses of the groundwater in the shallow aquifer.

Alternative 2: Cleanup to MCLs Throughout the Plume

This closure goal may be achievable with a combination of extraction technologies, engineered *in-situ* biodegradation, and monitored natural attenuation. The remedial action is likely to be costly, and may not achieve the remedial goal in a reasonable time frame. Strict interpretation of current California regulations for groundwater cleanups would require that this option be pursued, until it can be shown that further cleanup is not necessary for protection of human health or the environment and is not cost effective. However, from a risk perspective, such a remedial action is not warranted because of the current minimal risks to human health and the environment.

Alternative 3: Removal of FHCs from Subsurface to the Extent Practicable

Under this option, no specific remedial action goal would be selected, and the selected remedial action plan leading to closure would address only the removal of FHC mass to the extent feasible, given available technologies. Although this Site does not appear to pose unacceptable risks to human health and the environment, the groundwater contains a large dissolved BTEX plume, and there is evidence of significant amounts of residual product remaining in the water table aquifer. Furthermore, monitoring data do not show that the MTBE plume is stable. Thus, the FHCs released at the NEX Site continue to cause degradation of water quality due to the apparent continued migration of the COCs at the Site, particularly MTBE. Undertaking an active remediation program to halt plume migration, and to remove some of the residual product would decrease the time required for natural attenuation of the FHCs remaining after cessation of the active remediation program.

Alternative 4: Risk-Based Remedial Goals with Monitored Natural Attenuation

Because the Site appears to pose minimal risks, presumably setting risk-based goals would lead to a remedial action plan that would rely on monitored natural attenuation to remove the FHCs from the subsurface. Although there is evidence of aerobic and anaerobic degradation of the BTEX compounds at the Site, and it appears that the boundary of the BTEX plume is decreasing in size, data were not sufficient to determine the rate of these processes. Thus, the time required to achieve any risk-based goals could not be accurately estimated at this time. Furthermore, MTBE would continue to migrate, because this compound either does not easily degrade biologically, or if biodegradation occurs under aerobic conditions, it appears to be at a rate significantly slower than the rate of BTEX degradation under aerobic conditions. Thus, there are risks that this remedial strategy would not protect water quality, and that a greater volume of groundwater may be impacted. An evaluation of this option is recommended.

Alternative 5: National Test Site Applications

Since the Site is of major interest nationally as a part of the National Test Site Program a fifth alternative is suggested because of the unique character of this particular facility. Because the free-product plume and the BTEX plume appeared to be receding, it may be in the best interest of the National Test Site to allow various characterization and remedial technologies to take place with respect to both the free product and dissolved phase plumes. Even under active characterization and remediation of the free product and BTEX plumes, further monitoring should be required at this stage. At no time however, should the testing program allow any penetration deep into the fine grain sediments separating the upper and lower water bearing formations. With respect to the MTBE plume, the recommendation is to characterize the future direction of this plume with respect to the buried stream channel, recognizing that shallow utility lines along Patterson Avenue may result in a redirection of this particular plume. Further, a risk analysis needs to be considered for any discharge of the MTBE plume to drainage ditches in the area. If the MTBE plume continues to rapidly migrate, and if the risk analysis indicates that there is a potential for significant risk, then active remediation of MTBE should be considered. The EC recommends that any active remediation of the MTBE plume should be conducted under the direction of the National Test Site.

4.5. Uncertainties

MTBE was first added to gasoline as an octane enhancer in 1979, but did not become widely used in California until approximately 1986. California is one of fifteen states in the U.S. currently required to use reformulated gasoline which contains MTBE in order to meet the 1990 amendments to the Clean Air Act. Reformulated gasoline in California may contain oxygenates such as MTBE at concentration up to 11 percent by volume in order to meet the gasoline oxygen content requirements specified by the Clean Air Act and the California Air Resources Control Board. Although other oxygenates such as ethanol can meet the oxygen requirements for reformulated gasoline, MTBE has become the oxygenate of choice for a number of technical and economic reasons. As MTBE use has spread, the incidence of finding MTBE at sites that have experienced releases of fuel hydrocarbons has increased dramatically. Recent surveys have shown that MTBE is present in the groundwater at over 90 percent of the leaking UST sites.

Currently, MTBE is not a regulated chemical in drinking water at the federal or state levels, but due to recent legislation, California's Department of Health Services must establish a secondary maximum contaminant level (MCL) by July 1, 1998, and a primary MCL by July 1999. The human toxicity of the compound via ingestion is also uncertain, and EPA currently considers MTBE to be a possible human carcinogen. This can be compared to the current designation of benzene as a known human carcinogen. With respect to acute aquatic toxicity, MTBE appears to be significantly less toxic to organisms tested compared to benzene. MTBE taste and odor effects

may be perceptible to some portions of the population at levels as low as 5 µg/L. Because of this concern, EPA recently lowered its range of advisory levels for MTBE from 20 to 200, to 20 to 40 µg/L. Thus, recommended cleanup levels for this compound are likely to be between 5 and 20 µg/L, if the groundwater is a potential source of drinking water as defined by California State Water Code.

The presence of MTBE will limit the selection of monitored natural attenuation at many sites thought to be good candidates for this remedy because of the unique properties of MTBE. MTBE is only weakly retarded on soils, and in soils with organic carbon content less than 0.1 percent, MTBE will move at the same average rate as the groundwater. In addition, MTBE appears to degrade at a rate significantly slower than benzene or the other aromatic compounds of concern at a fuel hydrocarbon release. Under some geochemical conditions, not yet fully understood, MTBE may not degrade at all. As a consequence, those sites that previously may have been potential candidates for application of monitored natural attenuation may no longer meet the necessary conditions for this remedy, if MTBE is present.

Whether MTBE and other ether oxygenates, such as tertiary amyl methyl ether (TAME), or ethyl tertiary butyl ether (ETBE) will degrade in groundwater via abiotic or biotic mechanisms, is a current focus of considerable research. Early investigations provided ambiguous and conflicting results (references), which indicated that degradation, if it was occurring, was exclusively by means of biotic mechanisms. These early studies indicated that MTBE did not degrade under anaerobic conditions, but that under aerobic conditions, biodegradation may occur. Studies of abiotic degradation have thus far shown that MTBE will not degrade chemically, unless a highly oxidizing environment can be simulated, such as occurs in an ex-situ advanced oxidation process. Such conditions will not occur naturally in the subsurface.

More recent studies (Salanitro, 1994; Park & Cowan, 1997) have isolated microorganisms that can degrade MTBE in laboratory microcosms, provided that the oxygen content exceeds 2 mg/L. Recent field studies also report promising indications that MTBE will degrade aerobically in the subsurface, provided that sufficient oxygen is present (Javanumardian, 1997; Carter, 1997; Regenesis, 1998). A variety of studies have also shown, however, that in the presence of BTEX, and other relatively easily degradable organic compounds, MTBE degradation does not occur, presumably because of competitive inhibition between MTBE and the aromatic compounds. Shortage of oxygen may also explain these observed results, due to the presence of high concentrations of degradable compound that cause rapid exhaustion of the oxygen in the water.

The microbial kinetics of MTBE degradation are still under investigation, but results should be available soon that will permit estimates of MTBE degradation under a variety of geochemical conditions. It is likely, as has been reported by at least one investigator (Borden, 1997), that under optimum conditions in the subsurface, MTBE will degrade at a rate at least one order of magnitude less rapidly than benzene. Microcosm studies have also indicated that there is a significant lag phase that may extend up to one year before the microbial populations are capable of degrading MTBE. Under conditions of rapid groundwater movement, greater than 1 meter per day, this lag phase may result in very long MTBE plumes, which is the situation observed at Port Hueneme. Benzene degradation rates reportedly range from less than 0.1 percent to more than 1 percent per day, depending on the geochemical conditions. The average rate of benzene degradation observed in the LUFT study by LLNL was 0.8 percent per day, which translates into a half-life of about 86 days. Thus, the most recent data on MTBE biodegradation in groundwater suggest that if MTBE does degrade biotically, it will likely occur at the edges of the plume, and only when the MTBE migrates beyond the boundary of the BTEX plumes. Because of the apparent slow rate of growth of microbial populations capable of degrading MTBE, and the apparent long lag phase of microbial growth, the potential for long MTBE plumes that may adversely impact large volumes of groundwater is high.

The presence of MTBE at many UST sites in California has seriously derailed the movement to utilize monitored natural attenuation at many FHC release sites. Nonetheless, MTBE is not

particularly unique if placed in the context of the ASTM RBCA approach to remedy selection at FHC release sites. The presence of MTBE at a site can easily be integrated into a risk-based cleanup analysis. Fate and transport evaluations coupled with a clear definition of pathways and receptors will provide the necessary information to determine the appropriate remedy at such sites. Because MTBE is currently considered only a possible human carcinogen, risk assessments must be based on estimates of the hazard index. Groundwater designated as a likely source of drinking water, which may be impacted by MTBE migration, will require active remediation.

Other factors that may be evaluated include the likelihood of resource use and the value of the resource. In some of the RWQCBs in California, groundwater is considered to be a receptor, and thus, the presence of MTBE above drinking water standards would be sufficient to require active remediation, unless site-specific data could demonstrate that biodegradation was occurring at rates sufficient to stabilize and reduce the MTBE plume within target geographic boundaries.

Should active remediation of MTBE be required at a site, most of the existing remediation tools used to remediate BTEX releases can successfully be applied to deal with MTBE. Pump and treat has been shown to be a viable option, because MTBE is only weakly absorbed onto aquifer solids, and thus fewer pore volumes are required to achieve cleanup levels, compared to benzene. Treatment costs are increased because MTBE removal from water is generally more expensive than benzene removal, although cost differentials may not be significant compared to transactional and capital costs for the site. Air sparging has also been successful in removing MTBE from subsurface. Finally, reported successes using oxygen injection, or passive oxygen barriers, (oxygen releasing compound) indicate that engineered bioremediation may be applicable at some sites.

The current body of toxicological data for MTBE is limited. There are no studies of health effects on humans from long-term exposure to MTBE. All of the studies available for human hazard assessment are laboratory studies. The existing carcinogenicity data suggest that MTBE is a possible human carcinogen at high doses. The data do not support quantitative estimation of cancer risk at low exposures (U.S. Environmental Protection Agency [USEPA], 1997). Currently, there are several new carcinogenicity studies underway, but the results of these studies are not likely to become available before 1999. The existing toxicological data for non-cancer toxicity indicate that MTBE can pose a hazard of non-cancer effects to humans at high doses, and there are interim chronic reference dose values that may be used to estimate human health hazard at environmental exposures. Risk-based concentrations (RBCs) developed for soil and groundwater based on these reference doses, may not be protective of cancer effects if new studies indicate that MTBE is a more potent carcinogen than expected.

In addition, it should be noted that the site-specific RBCs provided to ARCADIS Geraghty & Miller for review are protective only of individual exposure pathways for a single chemical. In the event that multiple chemicals and multiple exposure pathways exist for an individual human receptor, the RBCs may no longer be protective because they do not consider additive effects of multiple exposures.

The taste and odor thresholds for MTBE in water and air are low. MTBE concentrations in water at the taste and odor threshold (5 to 40 $\mu\text{g/L}$) are not expected to cause adverse health effects because this concentration range is 4 to 5 orders of magnitude lower than the lowest concentration that caused observable health effects in animals (USEPA, 1998a). There are even greater margins of safety for MTBE in air. Therefore, remediation targets for soil and groundwater that are based on the odor threshold, are expected to be protective of human health and much lower than those calculated concentrations based on protection of human health.

Limited data have been published on the toxicity of MTBE to aquatic organisms. However, the available data indicate that MTBE is relatively non-toxic to marine fish and aquatic invertebrates with reported LC_{50} (concentration at which 50% of the test population died during a specified test duration) values falling between approximately 44 milligrams per liter (mg/L) and >2,500 mg/L.

MTBE appears to be significantly less toxic to aquatic organisms than other common volatile constituents of petroleum hydrocarbons products, such as ethylbenzene that has a secondary acute ambient water quality criterion of 0.43 mg/L. MTBE has a very low potential for bioaccumulation and does not pose a food-web risk as indicated by its log octanol/water partitioning coefficient (K_{ow}) of 1.24 (USEPA, 1994).

The USEPA and California RWQCB (San Francisco Bay Region) are currently working on draft guidance for a chronic marine ambient water quality criterion (AWQC) for MTBE. Based on current methods for criteria development and the available toxicity data, a chronic AWQC protective of marine organisms for MTBE is anticipated to fall between 1 mg/L and 3 mg/L (personal communication with Dr. Ravi Arulanantham, RWQCB).

MTBE behaves differently in soil, air and water than other constituents typically found in petroleum products. MTBE has a low molecular weight (88.15 grams per mole), high volatility (vapor pressure of 245 millimeters mercury at 25 degrees Celsius), and high water solubility (40-50 grams per liter) (USEPA, 1997). MTBE is about 30 times more soluble than benzene in water (USEPA, 1998b). Although MTBE has a greater vapor pressure (as illustrated by the low odor threshold) than benzene, when moving from the dissolved phase (in water) to the vapor phase, MTBE is about ten times less volatile than benzene. This is due to the high solubility of MTBE. MTBE is much less likely than other organic constituents to adsorb to soil or organic carbon and is resistant to biodegradation in the subsurface. This means that when MTBE is in the soil as a result of a petroleum release, it may separate from the rest of the petroleum, reaching groundwater first and dissolving rapidly (USEPA, 1998b).

The presence of MTBE will limit the selection of monitored natural attenuation at many sites thought to be good candidates for this remedy because of the unique properties of MTBE. MTBE is only weakly retarded by soils, and in soils with organic carbon content less than 0.1 percent, MTBE is expected to move at the same average rate as the groundwater. In addition, MTBE appears to degrade at a rate significantly slower than benzene or the other aliphatic or aromatic compounds of concern at a fuel hydrocarbon release. Under some geochemical conditions, not yet fully understood, MTBE may not degrade at all. This is demonstrated by the great distances MTBE has been observed to travel from a petroleum release into the subsurface.

USEPA and others have published some general summaries describing the toxicology and physical/chemical properties of MTBE that are referenced throughout this letter. These sources include the following:

- BenKinney, M. T., J. F. Barbieri, J. S. Gross and P. A. Naro (1994), "Aquatic Toxicity of Methyl-Tertiary-Butyl Ether (MTBE) to Aquatic Organisms," *presented at the 15th Annual Society of Toxicology and Chemistry Meeting*, Denver, Colorado, October 30–November 3, 1994.
- Boeri, R. L, J. P. Magazu, and T. J. Ward (1994), "Acute Toxicity Of Methyl Tertiary Butyl Ether to the Mysid, *Mysidopsis bahia* ," Study No. 424-AR. T. R, Wilbury Laboratories, Inc., Massachusetts.
- Mancini, E., and W. Stubblefield (1997), "Physiochemical and Ecotoxicological Properties of Gasoline Oxygenates," Abstract PWA 118, *presented at the Society of Environmental Toxicology and Chemistry 18th Annual Meeting*, San Francisco.
- USEPA (1994), "Chemical Summary for Methyl-Tertiary-Butyl Ether," *prepared by Office of Pollution Prevention and Toxics*, U.S. Environmental Protection Agency, August 1994.
- USEPA (1997), "Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl Ether (MTBE)," Office of Water Supply, December 1997.

- USEPA (1998a), "MTBE Fact Sheet #1—Overview," Office of Solid Waste and Emergency Response, January 1998.
- USEPA (1998b), "MTBE Fact Sheet #2—Remediation of MTBE Contaminated Soil and Groundwater," January 1998.

Closure of this Site will be difficult because uncertainties persist in understanding the flow path of the MTBE plume as it passes Patterson Avenue. These uncertainties must be addressed by Port Hueneme before a monitored natural attenuation remedial plan can be credibly advocated. The following discussion provides the EC's opinions on the significance of these uncertainties as they impact the selection of a risk-management strategy for this Site.

As noted in this Report, the EC feels that the Site has been characterized to a reasonable extent, but that data are still unavailable that facilitate a comparison of alternative risk-management strategies. These data include the following:

- A. Stability of BTEX and MTBE plumes.** Data indicate that in some portions of the groundwater, BTEX has stabilized but MTBE is still migrating and that the MTBE plume is not stable. Further groundwater sampling is recommended to determine whether the MTBE plume will stabilize.
- B. Potential for migration of FHCs to the deeper aquifer.** The EC has not reviewed data on the geology of the Site to determine the integrity of the aquitard separating the shallow aquifer from the deeper aquifer. Based on discussions with base personnel, it appears that the aquitard is thick and abandoned well conduits do not exist and thus, the potential for vertical migration is extremely low. This is a key issue if a monitored natural attenuation remedial alternative is selected and Port Hueneme has provided the regulators with the necessary evidence to support this position.
- C. Rate of natural attenuation.** Qualitative evidence (e.g., geochemical indicator parameters) of passive bioremediation of FHCs is available from site groundwater monitoring data. However, the observed BTEX plume length at the Port Hueneme Site (greater than 1,000 feet) is not consistent with the LUFT historical case analysis results, ranking above the 99th percentile. This suggests that either the rate of passive bioremediation at the Site is very slow or that other factors are contributing to the unanticipated long plume length. One factor may be the high flow velocity in the pale channels at the Site; several hundred feet per year based on hydraulic conductivity values and the hydraulic gradient. Using analytical models of an idealized flow and transport regime, such high groundwater velocities may be shown to produce long FHC plumes (greater than 1,000 feet) even under typical passive bioremediation rates (0.1% to 1% day⁻¹). This seems a logical explanation, as there are no apparent typical site-specific conditions which would be expected to substantially reduce the passive bioremediation rate. Additional sampling will permit further assessment of the MTBE plume behavior. Because the rate of MTBE transformation is significantly less than that of other FHCs, if transformation occurs at all, the MTBE plume should exhibit a greater tendency for continued migration in comparison to BTEX. The high groundwater velocities at the Port Hueneme Site would be expected to exacerbate this phenomenon. As such, an active engineered approach for remediation of the MTBE plume should be considered if the ecological assessment indicates high risk.
- D. Rate of volatilization.** It is likely, that FHCs at this Site are subjected to significant volatilization because of the warm climate and the relatively shallow depth to groundwater. However, the soil gas data does not support this hypothesis, although it is conceivable that significant volatilization has already occurred, or the residual product is submerged beneath the water table.

5. Summary and Recommendations

5.1. Sources

FHCs have impacted the groundwater at the NCBC NEX Gasoline Station at Port Hueneme, California. The primary sources of FHC releases, are former USTs. Secondary sources of FHCs are still present, primarily as residual product that represent a continuing threat to groundwater quality. There is evidence of significant secondary source reduction due to volatilization and biodegradation of the BTEX compounds in at least a portion of the contaminated groundwater. MTBE concentrations in numerous monitor wells exceeds the current DHS action level of 35 µg/L, by three orders of magnitude and the amount of MTBE present in the existing secondary sources is very high.

5.2. Pathways

Two major pathways of concern at this Site are the water table aquifer and soil vapor. The boundary of the BTEX plume has been decreasing in size, but the MTBE plume appears to still be migrating and appears to have moved 2,000 feet past the apparent edge of the BTEX plume.

Soil gas results demonstrate that the vapor pathway is incomplete due to biodegradation of BTEX vapors and depletion of the residual FHC pool.

5.3. Receptors

The drainage ditches at Pennsylvania Road and at Pleasant Valley Road may have human and ecological receptors. Potential human receptors exist in the vicinity of the Site, and hypothetical receptors, such as future onsite or offsite workers, can be considered as potential receptors of exposure via the soil gas pathway. However, the current lack of complete exposure pathways demonstrates that no receptors are currently at risk from FHCs released from the NEX Station.

A full evaluation of the location of an abandoned water well has shown that these old maps were inaccurate and that the abandoned water wells are not in the area of concern. Conflicting maps have been located and the regulators are comfortable that the substantial field investigations demonstrated that the old abandoned water well is not within the confines of the contamination plume.

5.4. Risk-Management Strategies

The MTBE plume at the NEX Site represents a challenge. No further action for BTEX is recommended. If the MTBE plume continues to migrate, further assessment of the ultimate impact on groundwater resources in the area must be considered. Although MTBE does not appear to pose significant risks to human health and the environment, MTBE can degrade water quality, and a larger volume of groundwater will likely be impacted.

Natural attenuation as the preferred risk-management strategy for the entire Site may not be acceptable because of the high values of MTBE observed.

An evaluation is needed to support a risk-management strategy of natural attenuation. However, it is necessary to estimate how long natural attenuation will take to restore the groundwater to acceptable cleanup levels. This may be difficult given uncertainties in the fate of MTBE.

A unique approach to risk management should be considered as a part of this Site strategy. Since the entire contamination plume is under major investigation with partial remediation as a part of the National Test Site program, it is reasonable to leave free product in place, continue to study the BTEX plumes and to utilize the fact that the MTBE plume is of substantial length with many characteristics that require further evaluation. As such, the MTBE plume offers an excellent opportunity of the National Test Site to develop innovative techniques to characterize and potentially remediate MTBE.

5.5. Recommendations

The EC recommends that Port Hueneme conduct additional MTBE site characterization, and monitoring to determine whether natural attenuation is an acceptable risk-management strategy at this Site. The site characterization should result in a further delineation, of the preferred flow channel to help determine the further migration pathway of the MTBE plume. Although current estimates place the MTBE plume at the drainage ditch in approximately four years, an ecological risk assessment should be made. If the risk assessment shows unacceptable risks, an active remediation program should be implemented.

6. References

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- Rice, D. W., R. D. Grose, J. C. Michaelsen, B. P. Doohar, D. H. MacQueen, S. J. Cullen, W. E. Kastenberg, L. G. Everett, and M. Marino (1995b), *California Leaking Underground Fuel Tank (LUFT) Historical Study*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-122207).
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Appendix A

Review of Naval Exchange Gasoline Station Naval Construction Battalion Center Port Hueneme Site Assessment to Apply Risk-Based Corrective Action

MEMORANDUM

TO: Department of Defense
Petroleum Hydrocarbon Demonstration Project
Expert Committee Members

FROM: Lorne G. Everett

DATE: January 23, 1997

RE: Review of Naval Exchange gasoline station, Naval Construction Battalion Center, Port Hueneme site assessment to apply risk based corrective action.

The Department of Defense (DOD) Petroleum Hydrocarbon Demonstration Project (PHCDP) Expert Committee (EC) has review the methods and findings of site environmental investigations conducted at the Naval Exchange (NEX) gasoline station at the Naval Construction Battalion Center at Port Hueneme, hereafter referred to as the "Site".

The Site investigations at the NEX have been conducted for the purpose of:

- Characterizing the subsurface release of petroleum hydrocarbons,
- characterizing the impact of the release on the beneficial uses of groundwater resources of the State of California, and
- providing a credible basis for applying risk-based corrective action (RBCA) to achieve site closure.

SOURCES

Since the beginning of operations of the NEX gasoline station in 1950, twelve tanks have been installed for storage of gasoline at the Site. Eight of the tanks have been removed and currently only four tanks are operational at the Site. All of the tanks ranged in volume from 7,400 gallon capacity to 12,000 gallon capacity with the exception of a single 350 gallon capacity tank which, although classified as storing gasoline, was probably a waste oil tank. Although the eight tanks were removed between 1992 and 1993, no information is available regarding possible leakage prior to 1984.

A field study began in 1984 and 1985 which indicated that product delivery lines between the UST and the pumps were leaking badly. No indication is given as to whether the tanks and current delivery lines are leaking or not. Both MTBE and 1,2-DCA were contained within the gasolines which were identified back in 1984.

Product only remediation pumping systems installed in 1987 are not supported with any records which indicate whether the system was ever operated or why the system was not put into operation. Since the primary source of contamination, i.e. the leaking tanks and pipelines have been removed, a statement needs to be made that the existing tanks and pipelines have been tested and shown to be tight. The secondary source associated with soils and free product have been in evidence through a Step 1, Step 2, Interim Corrective Action Program and subsequent activities which have identified the presence of free product in the area of the NEX gasoline station.

Each NEX investigation appears to show that the previous investigation was not conclusive. Although a final corrective action plan was developed, the approach was not implemented because in 1995 the NEX gasoline station became the Hydrocarbon National Test Site (HNTS) for the evaluation of innovative treatment systems. The HNTS, however, took over a site which was poorly characterized in the past.

SITE CONCEPTUAL MODEL

Although a generalized geologic cross-section is provided for the Site, no indication is given for the lateral and vertical distribution of contaminants in soils. In addition, the generalized hydrogeologic cross sections are regional and provide very little insight into the vertical distribution or the understanding of soils at the NEX station. As such, the vertical and horizontal distribution of soils and contaminants in the vadose zone are not represented or discussed. The groundwater data suggests that the petroleum hydrocarbon plume at the NEX gasoline station has increased over time, and currently is not fully characterized. In addition, MTBE concentrations on the downgradient edge of the plume appears to be increasing and has not been fully characterized. The extent of the free product at the Site is not currently delineated due to the effects of experimental remediation systems and the seasonal groundwater fluctuations. As such, the vadose zone and saturated zone, vertical and horizontal distribution of product, BTEX, hydrocarbon, and MTBE need to be delineated.

In Figure 16, it appears that there may be an additional cross gradient source of contamination as evidence by the elevated BTEX concentrations associated with Well CDC-33 located north on Dodson Street.

PATHWAYS

Three potential migration pathways are identified at the Site. The first consists of VOC migration from contaminated soils and groundwater up through the vadose zone to the surface. No data is provided to determine whether this upward pathway results in soil gas concentrations which may have an associated health risk.

The second pathway involves contaminated water traveling from the semi-perched aquifer to deeper producing aquifer wells in the vicinity. Although the statement is given in the report that the second pathway is probably not complete "No evidence is given that the deeper aquifer wells are unaffected by the shallow contamination." An indication, however, is given that old, abandoned, deep water wells in the area may provide a conduit to the deeper water bearing formations, and as such, a complete field inventory and survey of abandoned wells and evidence of appropriate abandonment.

The potential for dissolved contaminants in groundwater to migrate to surface water drainage ditches and eventually to the harbor constitutes a third pathway. Based on the proximity to drainage ditches and the harbor, it appears that this third pathway is highly unlikely at this time. No evidence is provided for VOC migration through soils from soil and groundwater contamination which may effect humans. Although the semi-perched aquifer is not used for drinking water purposes, evidence has not been provided that the Hueneme aquifer zone has not been contaminated by the shallow contamination, and as such, the potential for human receptors using these deeper water bearing formations exists. Receptors associated with the possibility of surface water drainage have not been identified.

LAND USE OPTIONS

It appears that all twelve of the former tanks and existing tanks are in approximately the same location, and as such, it appears that the gas station has historically been at this location and will continue on to the future. However, in the area downgradient from the NEX station, it appears that the land use activity has changed over time, and as such, no insights are provided to either receptors or land use activity downgradient which should be considered as a part of an overall risk management strategy.

RECOMMENDATIONS

Outside of limited references to oxygen and nitrate, very little information is provided to demonstrate that either aerobic or anaerobic degradation is taking place within the plume. In fact, it appears that the plume, both vertically and horizontally has not been characterized to date. Consideration needs to be given to why the BTEX and MTBE has moved so far downgradient in an area of relatively flat hydrogeologic conditions. The role of subsurface sewage lines, utility lines, etc. needs to be evaluated as a part of this Site since the utility lines are located at approximately 8.5 feet and the groundwater is typically encountered at 8-10 feet below grade. In addition, not a single potentiometric map is provided at the Site to develop a feeling for groundwater flow gradients and direction.

Although the BTEX distribution has not been fully defined, emphasis should be placed on the very high levels of MTBE identified at the downgradient leading edge of the plume. The MTBE behavior needs to be better understood relative to what may be a natural flow path as opposed to a behavior highly dependent upon the various remediation programs which are in place at the Site. Emphasis, therefore, needs to be placed on making sure that the old deep water supply wells have been located and properly abandoned and the MTBE plume is better characterized. Since the plume has not been characterized to-date, a risk based evaluation cannot proceed until a better understanding of how and why the plume is continuing to migrate.

Appendix B

Addendum to Review of Naval Exchange Gasoline Station, Naval Construction Battalion Center Port Hueneme Site Assessment to Apply Risk-Based Corrective Action

MEMORANDUM

TO: ENS Holly M. Jenkins
Code 40
1000 23rd Ave.
Port Hueneme, CA 93043-4301

FROM: Dr. Lorne G. Everett

RE: Review of Naval Exchange Gasoline Station, Naval Construction Battalion
Center, Port Hueneme Site Assessment to apply risk based corrective action.

The Department of the Navy Engineering Field Activity West Naval Facilities Engineering Command San Bruno, CA on July 2nd 1997 provided an addendum to the briefing package of December 5th 1996. This addendum satisfies the site assessment concerns expressed in my earlier letter dated January 23rd, 1997.

In my opinion, the Lawrence Livermore expert committee is now in a position to complete the Risk Management Report. Prior to the submittal of the Risk Management Report, however, I believe, it is good practice to cleanup a number of issues which surfaced as a part of the preparation of the addendum. These issues are more along the line of correction and are listed on a separate page.

Thank you for this substantial effort which included both a very active field characterization and analytical program and a substantial document review effort.

Sincerely,



L.G. Everett
Chief Research Hydrologist and Vice President

cc: Michael Pound, Expert Committee

LGE:tlb

Addendum Correction Sheet for July 2, 1997 Submittal

- Page 2, bottom sentence refers to building 797. Building 797 could not be found on location map.
- Page 2, bottom sentence says the "NEX gasoline station..., at the southeast intersection of 23rd Avenue and Dodson Street, since 1950." Appendix C covering the SCAPS investigation, Page 1 under 2.1 General Site Background says, "The former NEX gasoline station site is located on NCBC Port Hueneme at the southwest corner of 23rd Avenue and Dodson Street." Which location for the NEX gasoline station is the agreed upon location?
- Page 3, top sentence, reads, at that time, two 7,400 gallon UST, were installed. The fate of these two USTs are not expressed. In addition, the discussion of underground tanks leaves the impression that four tanks are either still in the ground or have been removed without documentation.
- Page 2, bottom line, there is an indication that 1,2-dichloroethane (1,2-DCA) was released with the MTBE and yet there is no further discussion of the 1,2-DCA.
- Page 5, 30.3 where it refers to 7 monitoring wells, Figure 1 should be referenced so as to be able to locate these wells.
- Page 5, 3.4, the reference to West Tech 1988, should be West Tech & Stolar, 1988.
- Page 6, top line, reference is made to the capillary fringe and near the spill source Figure 2. Unable to locate Figure 2.
- Page 7, top bullet, reference is made to Well CBC-1 abandonment and yet no discussion is given for how this well was abandoned. Second bullet refers to extraction wells CBC-20 through CBC-23 and yet on the second bullet from the bottom talking about extraction wells CBC-20 is not included.
- Page 7, the 50 hour, 100,000 gallon pump test is identified and yet, this major pump test impact on local hydrogeology is not discussed.
- Page 7, second bullet from the bottom, reference is made to CBC-18 being an extraction well and yet it is not identified earlier in the page as an extraction well. On the bottom bullet reference is made to three proposed, large diameter extraction wells. These extraction wells are not identified and perhaps this would clear up the confusion in this section.

- Page 7, 3.7, reference is made to CBC-17 and yet the description of this well could not be found.
- Page 7, three lines from the bottom, it says "Free phase product was noted during UST removal." The implication was that free phase product was removed at each of the eight USTs removed. Is that correct?
- Page 8, third bullet from the bottom, reference was made to CBC-91, this well could not be located.
- Page 9, section 3.9, second sentence from the bottom, it states, "Currently, the three UVB-200 wells are operating as a bio-curtain system." Evidence, to date, indicates that these wells are not operating as a bio-curtain system.
- Page 10, Reference to Battelle 1996. This reference does not appear in the list of references.
- Page 10, item 3-10, does not make reference to the cross borehole electrical resistance tomography or the cross borehole radar tomography. In addition, specific sampling technologies and water direction measurement technologies are not mentioned.
- Page 10, item 4.1 refers to the integrity testing of the tanks and typing for the current field system are provided as Appendix B. The reference in Appendix B is to EBW Tank Guard as the system manufacturer and yet, the individual conducting the test refers to the system as Leak Alert equipment. Is this Leak Alert equipment or EBW Tank Guard equipment. It is difficult to tell from the poor fax that was submitted as to whether this is simply a system certification form or whether the system has been tested to be tight.
- Page 11, top paragraph refers to the petroleum hydrocarbon plume as confined vertically and horizontally to the capillary fringe and the upper few feet of the saturated zone of the semi perched aquifer. Data to support this contention both in terms of text, tables, or figures could not be found.
- Page 11, 4.3 groundwater data, reference is made to a free product sheen or smear zone. The smear zone implies tidal pumping, or water level fluctuations which could cause this smear zone. Evidence of a smear zone has not been provided. In addition, the opening page of the report spoke to 1,2-DCA and yet, in the discussion of groundwater data, no reference is made to 1,2-DCA.
- Page 12, 4.3.2, MTBE Plume, no attempt is made to provide a figure showing contours related to MTBE.

Page 12, reference is made to CBC-53 and yet this location could not be found on a figure. In addition, reference is made to a cone sipper push 42 and yet no reference could be found for this location on a figure.

- Page 12, reference is made to the elongated MTBE plume resulting from a paleo-stream channel acting as a preferential flow pathway. Did this pathway also provide a preferential flow path for BTEX.
- Page 12, 4.3.2, reads, "Additional groundwater monitoring is planned to determine if the MTBE plume has stabilized." My understanding is that the MTBE plume has been characterized and a testing program has been developed to show the approximate end of the plume longitudinally and transversely and therefore if additional MTBE characterization is to take place, the Livermore team would appreciate the opportunity to evaluate the results.
- Page 12, and 13 under 5.1 Vapor Migration, no reference is made relative to potential gas buildup under the gas station. This gas buildup could either be methane or BTEX. In addition, no reference is made to gas migration in sewers, utility lines, flood control lines, etc. which could be conduit for explosive gas mixtures.
- Page 13, 5.2.1 refers to an agricultural supply well, AM-1. No figure is provided to show the approximate location of this well nor is there any indication whether this well was potentially downgradient. Reference is only made to the fact that the well did not appear to be in the dissolved phase portion of the plume.
- Page 14, related to 5.2.2 Drinking Water Wells, no indication is given as to the distance between the first drinking water wells encountered and the source of the contamination.
- Page 15, 6.1 Human Reception, no reference is made relative to explosion potential. In addition, evidence is provided that the BTEX plume is shrinking and yet no contour maps are provided to show the reduced plume size.
- Page 16, 7.1, Nitrate and Bacterial Counts, the first sentence reads "Both nitrate concentrations and fuel degrading bacteria counts around the edge of the BTEX plume appear to be decreasing with time." When checking Figure 9, it shows that the nitrate concentrations are increasing with time.
- Page 16 refers to the air sparging system as occurring within the central portion of the BTEX plume. My understanding would place the airsparging system in the downgradient portion of the plume as opposed to the central portion of the BTEX plume.

- Page 16, 7.2, Preferential Flow, reference is made to the utility lines. The arguments presented related to the fact that the utility lines do not intersect the water table and do not follow the groundwater gradient miss the issue related to utility lines having a higher permeability typically than the surrounding environment thereby allowing contamination to move preferentially in the vadose zone independent of groundwater flow gradient and intersection to the water table.
- Page 16, 7.2, reference is made to CBC-53 wherein this particular well was not able to be located in any figure.
- Page 17, reference to list of wells to be sampled, specifically excludes CBC-53 which could not be located earlier.
- Page 17, bottom paragraph, reference should be made relative to the potential buildup of explosive gases below the buildings.
- Page 18, the question still remains relative to finding all of the tanks. In addition, it appears that there may be an additional source upgradient of the NEX gasoline stations which has not been evaluated.
- Page 18, 9.0, the quality of how references are used in the text and in the reference section needs to be improved. For example, ERC is also referenced as to ERCE, James N. Montgomery is also referenced as JNM, PRC Environmental Management, Inc. is just referred to as PRC, SCS, however, is referred to as Sterns, Konrad and Schmidt.
- Figure 1, two different locations have been provided for the gas station. In addition, Figure 1 does not indicate which wells are monitoring wells and which wells are extraction wells. Figure 2 is not the cross section figure. Figure 2 does not provide insight into channel distribution nor does it describe why we have circles around two separate groupings of wells. Figure 3, has any continuous layers been found at the facility? Figure 4 does not indicate if this is groundwater or soil nor does it indicate the units of measurement. Figure 5 does not indicate that the MTBE concentrations are in groundwater and the units provided in Figure 5 are incorrect. The units for MTBE are parts per billion not milligrams per liter. Figure 6 does not indicate that these are groundwater samples nor does it indicate the appropriate units. Figure 9 should read "Nitrate concentrations in groundwater" and shows that nitrate is increasing in time whereas in the text it is referred to as decreasing in time. Figure 11 which demonstrates a substantial number of data points, illustrates one equal potential line.